Nix, A. R., Hafezi, P., Sun, Y., & Beach, M. A. (1997). Overview of the AWACS testbed. (pp. 9 p).

Overview of the AWACS testbed

A. Nix, P. Hafezi, Y. Sun, and M. Beach

Centre for Communications Research, University of Bristol
Merchant Venturers Building, Woodland Road, Bristol BS8 1UB, UK

1. Introduction

The ACTS AWACS (ATM Wireless Access Communication System) project [1] is addressing the feasibility of directional antenna technology as a viable alternative to equalisation and multi-carrier techniques for the provision of ATM compatible bit rates over a wireless bearer.

The AWACS system project has set its target on the development of a system concept and a testbed demonstration of wireless public access to B-ISDN services. AWACS is based on 19 GHz hardware (AWA pre-prototype [2]) developed by NTT and made available to the consortium to support field trials and system concept studies. The AWA pre-prototype is a full duplex wireless modem based on a TDMA/TDD frame structure, allowing maximum and minimum bit rates of approximately 23 and 1.5 Mbit/s respectively in a given direction.

This paper discusses the AWACS test-bed and includes the specification and configuration of the AWA pre-prototype modem and channel sounder. A summary of the measurement results and conclusions drawn from the programme to date are also included in this contribution.

2. AWA Pre-Prototype Configuration

The AWA pre-prototype equipment is based on a 19 GHz ATM compatible modem (see figure 1), which was developed by NTT and made available to the AWACS consortium as the hardware basis for a number of trials and system concept studies.

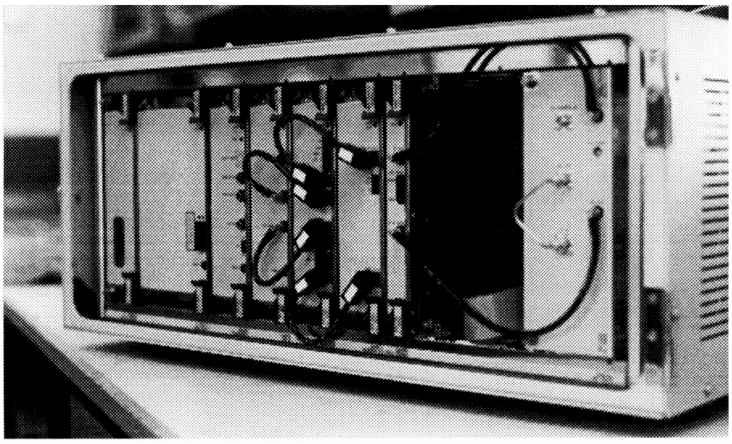


Figure 1: Prototype Wireless ATM System (NTT)

The equipment consists of a Broadband Central Station (B-CS: base station) and a Broadband Radio Module (B-RM: personal station). Each is contained in one sub-rack (65 x 26.5 x 57.5 cm) and the total weight is 25 kg. The front panel arrangement is shown in Figure 2. This figure indicates a CS with diversity reception based on two RF circuits (RF CKTs). The RM has no diversity reception since this reduces the price, weight, and volume. The equipment deployed at Bristol has no diversity reception, however the final AWACS trial at Elektrobit in Finland will make use of this technology.

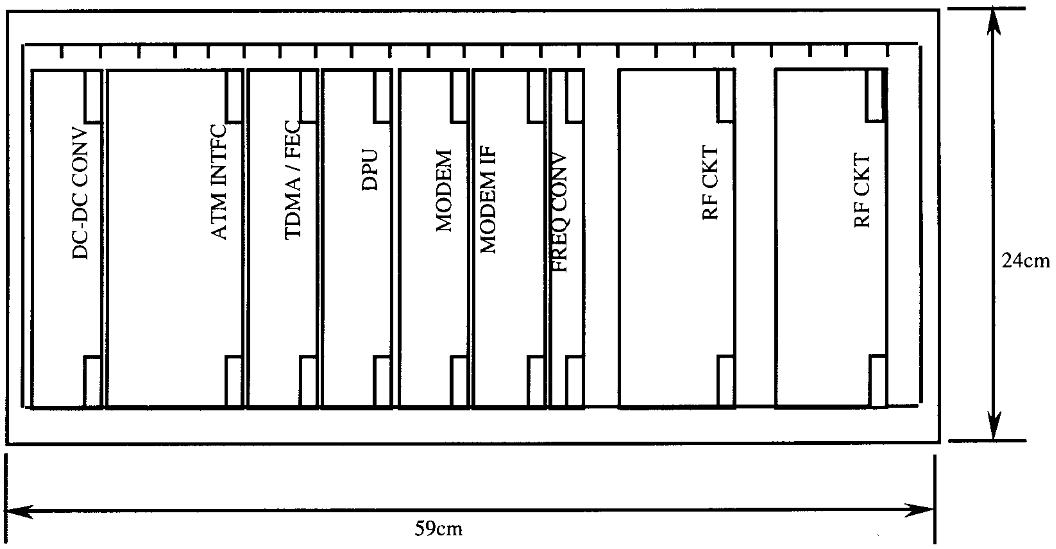


Figure 2 - Front View of AWA Pre-Prototype Equipment

The equipment's configuration is illustrated in the block diagram shown in figure 3. Both the B-CS and the B-RM have the same configuration except for the B-CS's additional RF CKT for diversity reception. The system consists of transmitter and receiver parts, and are basically composed of the following panels:

(1) ATM INTFC;

- Terminate ATM header,
- Extract valid ATM cells from 155.52 Mbit/s OC-3c input data,
- Compose 155.52 Mbit/s OC-3c output data including received valid ATM cells.

(2) TDMA/FEC;

- Add FEC parity bits,
- Correct errors.
- Generate a transmitter and receiver switching signal

(3) Data Packet Unit (DPU);

- Compose radio-section frame,
- Control transmitting and receiving burst data timing,
- Establish unique word synchronisation.

(4) MODEM;

- Modulate 35 MHz carrier by radio section data,
- Demodulate radio section data.

(5) MODEM IF;

- Convert 35 MHz IF modulated signals into 140 MHz IF modulated signals,
- Convert 140 MHz IF modulated signals into 35 MHz IF modulated signals.

(6) FREQ CONV;

- Convert 140 MHz IF modulated signals into 850 MHz IF modulated signals,
- Convert 850 MHz IF modulated signals into 140 MHz IF modulated signals,
- Generate an SD control signal from 140 MHz IF main/sub received signals in only B-CS.

(7) RF CKT;

- Convert 850 MHz IF modulated signals into RF modulated signals,
- Convert RF modulated signals into 850 MHz IF modulated signals,
- Switch circuit paths between the Tx and the Rx using the TDMA/FEC's switching signal,
- Switch received signals between main and sub inputs using the FREQ CONV's SD control signal in the B-CS.

The equipment receives and transmits its data via an OC-3c input/output interface. This interface provides a data rate of 155 Mbit/s. Figure 3 also includes certain nominal power levels at major points in the block diagram. These levels are shown for the case where the B-CS is transmitting to the B-RM (downlink).

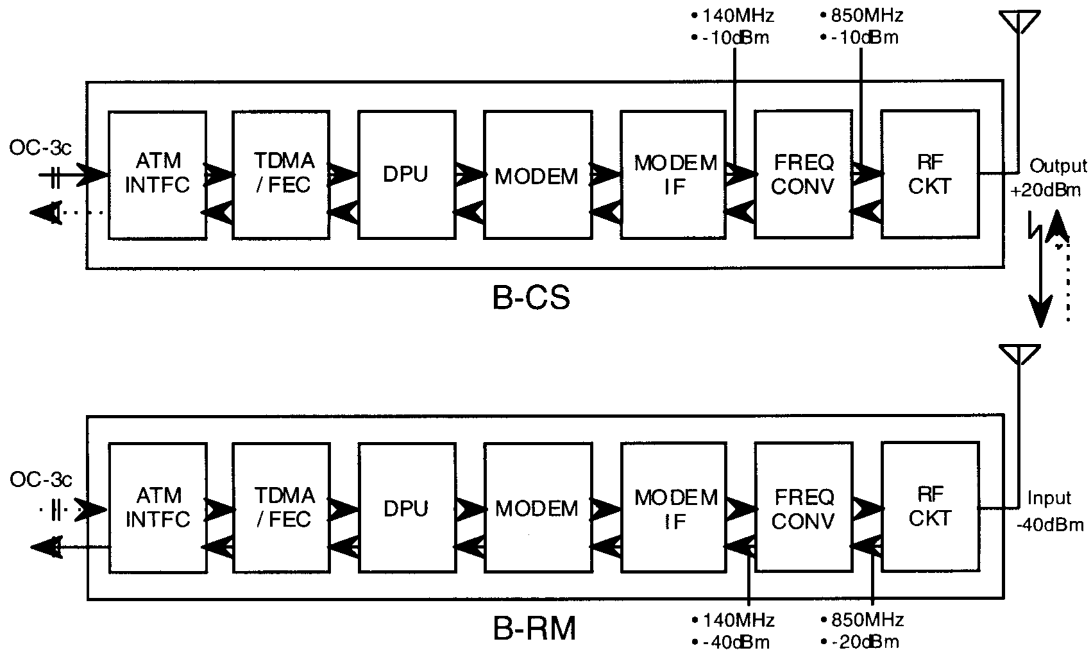


Figure 3 - Configuration of AWA Pre-Prototype Equipment

The AWA test-bed makes use of a highly directional antenna at the B-CS to help mitigate the harmful effects of the radio channel. If necessary, antenna directionally can also be used at the B-RM. One of the main goals of the AWACS trial is to determine the necessary beamwidths required for near error free communications at instantaneous bit rates in the region of 70 Mbit/s.

3. Major Specifications

Table 1 shows the major radio specifications for the AWACS test-bed. To control spectrum shaping, the equipment uses a raised cosine roll-off filter with a roll-off factor of 0.4. The receiver currently makes use of non-linear devices, such as a limiter amplifier. The limiter amplifiers are used to keep the received signal at a constant level. The required total dynamic range of the limiter amplifiers is more than 43 dB.

To protect the data, Forward Error Correction (FEC) coding is used. The equipment uses two types of Reed-Solomon FEC code for the ATM cells. An RS(14,8,3) code is used for the ATM header and can correct up to three bytes. The ATM payload data is protected using an RS(50,48,1) code, offering a one byte correction capability.

Item	**Specification**	**Remark**
Centre frequency	19.37GHz	
3dB RF bandwidth	35.1MHz	
Transmitter		
Output power	20dBm	
TDD switch insertion loss	less than 2dB	
RF frequency stability	Less than 3×10^{-6}	
Receiver		
NF	Less than 10dB	
RF Frequency stability	Less than 3×10^{-6}	
Receiving level monitor	Dynamic range : 30 dB	
Modulation		
Modulation scheme	Offset QPSK	
Modulation bit rate	70.208 Mbits/s	
IF frequency stability	Less than 3×10^{-4}	
Spectrum shaping	Cosine roll-off ($\alpha = 0.4$)	100% Spectrum shaping in MOD
Demodulator	Absolute coherent detection	
Limiter amp	Dynamic range more than 46dB	
Access Mode	TDD/TDMA	
FEC (Header)	RS Code (14,8,3)	3 Byte correction
FEC (Payload)	RS Code (50,48,1)	1 Byte correction
Frame structure	See Fig. 2.3 and Fig. 2.4	

Table 1: Major Specifications for the NTT AWACS Test-Bed

4. Frame Format

Figure 4 illustrates the frame format used in the AWACS air interface. The test-bed is based on a TDMA-TDD frame format. The frame consists of 16 time slots for each forward or reverse link, with each frame having a duration of 2 ms. In the AWACS test-bed, the fixed allocation of up and down link time slots has been removed and it is therefore possible to achieve asymmetric data transmission rates.

The lower section of Figure 4 shows the structure of the frame during each time slot. The time slot includes 8 ATM cells (each containing 48 bytes) together with the necessary FEC parity bits. The user bit rate is 1.5 Mbit/s per time slot, taking into account the frame duration of 2 ms. The equipment uses two fully digital VLSIs for its modulator and demodulator. These were developed by NTT [2]. The equipment uses Offset QPSK (OQPSK) to modulate the data onto the RF carrier. Each frame also includes carrier recovery (CR) and the bit-timing recovery (BTR) words to enable successful reception. Furthermore, ramp time bits and guard time bits are also added to the frame structure. The total number of bits per time slot is 4388 and the total duration per slot is 62.5 microseconds (i.e 70.2 Mbits/s).

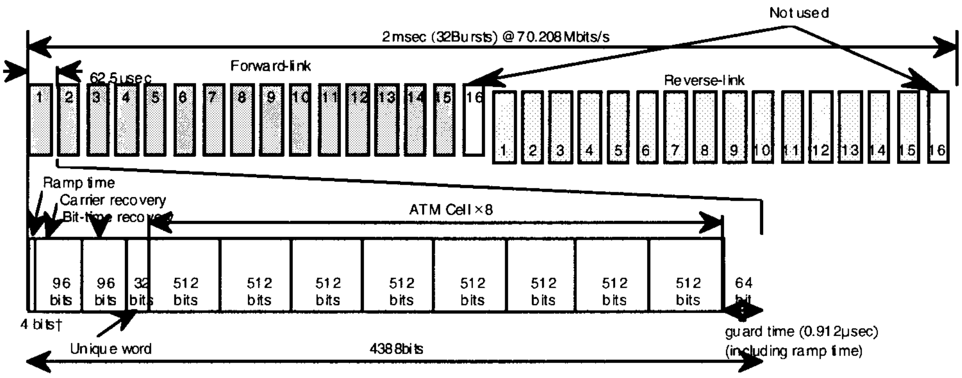


Figure 4 - Frame Format used in the AWACS Air-Interface

Figure 5 shows the frame format used for each burst. There are 512 bits (64 bytes) for the data in each ATM cell as shown in Figure 5. This data consist of 53 bytes for the ATM cell, 8 bytes for the FEC parity, and 3 bytes for the idle data.

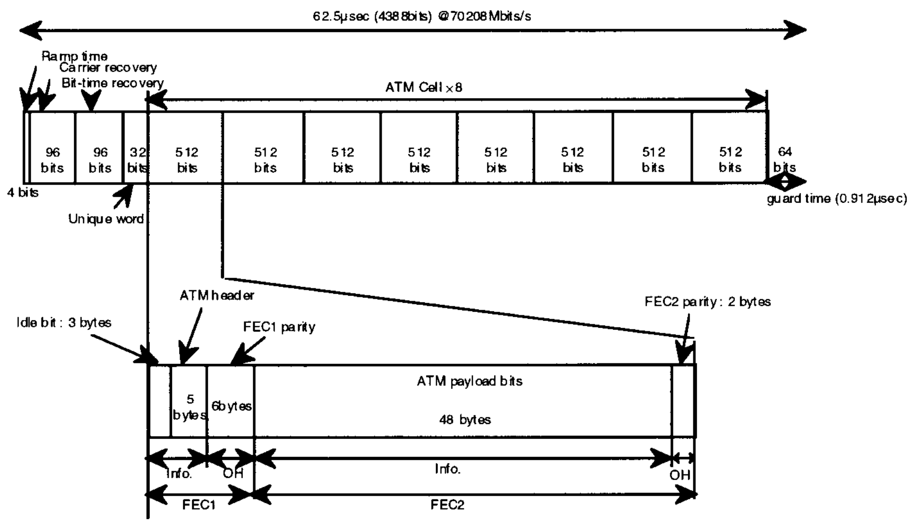


Figure 5 - Frame Burst Format

5. Wideband Channel Sounding System

To enable wideband propagation measurements to be taken, a sliding correlator [3] channel sounder has been integrated into the test-bed. The sounder was interfaced to the ATM transmission equipment via an intermediate frequency (IF) of 850 MHz. This signal was then up converted to the final carrier frequency of 19.37GHz. In Europe, the 17.1 to 17.3 GHz band has been allocated for Hiperlan type 4 operation, however in terms of wideband propagation analysis, 19.37GHz is considered to be representative of the Hiperlan type 4 band. Appropriate modifications were made to the transmit and receive filters of the NTT prototype equipment in order to support the full resolution of the sounder [4][5].

The transmission equipment employed during the measurement campaigns was configured as a uni-directional system, i.e. from the Base Station (BS) to the Mobile Station (MS). Furthermore, the spreading sequence within the transmitter was clocked at 100Mchips/s, and a 4kHz offset frequency was employed within the receiving system of the sliding correlator sounder. The analogue IQ outputs were then digitised and stored on a PC for subsequent post processing using MATLAB. Using the software suite developed under AWACS, the channel impulse response (CIR) and received power can be directly observed, as well as statistical parameters, such as delay spread and Rician K-factor.

The integrated modem and channel sounder allows the AWACS test-bed to be used to measure systems parameters such as bit error rate and cell loss rate, or propagation parameters such as received power, K-factor and rms delay spread. Analysis of these parameters for different Tx and Rx antenna configurations can then be used to determine the most appropriate configuration for a future system.

6. Measurement Locations

Various indoor locations were considered during the measurement campaigns at the University of Bristol. The results summarised in this paper correspond to the entrance foyer in a modern building and an open plan office area. Further details can be found in [4][5].

6.1 Entrance Foyer of a Modern Building: Site 1

This location was chosen since it represents a large open indoor environment where line of sight (LOS) and non line of sight (NLOS) scenarios can easily be studied. Figure 6 shows the plan of the location, and the position of the BS and MS units. It is worth noting that there is a large metal surfaced column in the foyer, and the MS route along *A-B-C* is free from any obstacles. However, along the path *C-D-E-B,* the LOS will be blocked by the column.

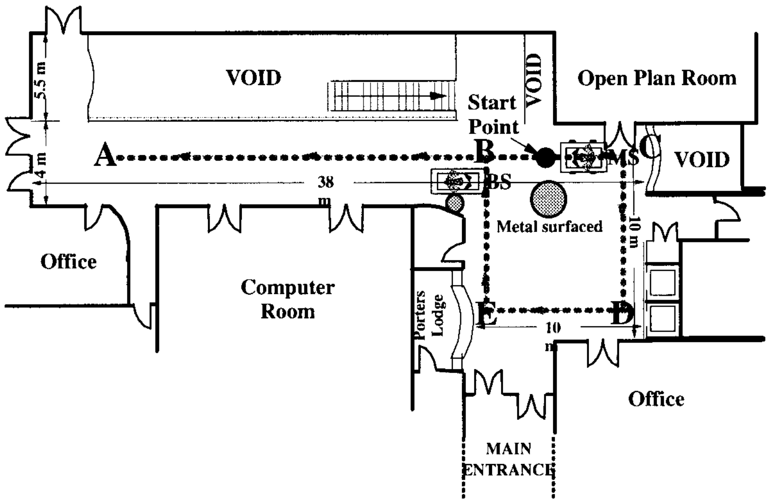


Figure 6: Plan of Foyer and locations of BS and MS

A number of other sites were also chosen and a full description of these environments can be found in [4-5].

7. Measurement Campaign and Analysis

Four different types of antenna were employed during the trials: omni-directional, 60° and 30° beamwidth patch, and a 15° beamwidth horn. The corresponding gain of these units in the azimuth plan was 0dBi, 10.9dBi, 14.1dBi and 21.0dBi respectively.

7.1 RMS Delay Spread Analysis

Using the channel sounding system briefly described in section 5, the rms delay spread distribution of the foyer (figure 6) and a large open plan office were obtained. For each set of measurements reported in this section, the antennas were manually aligned to face each other. If objects blocked the line of sight path, this alignment procedure was still adopted. This exercise was repeated for six different antenna combinations for both the foyer and the large open plan office areas. The resulting cumulative distribution results given in figures 7 and 8 were then obtained.

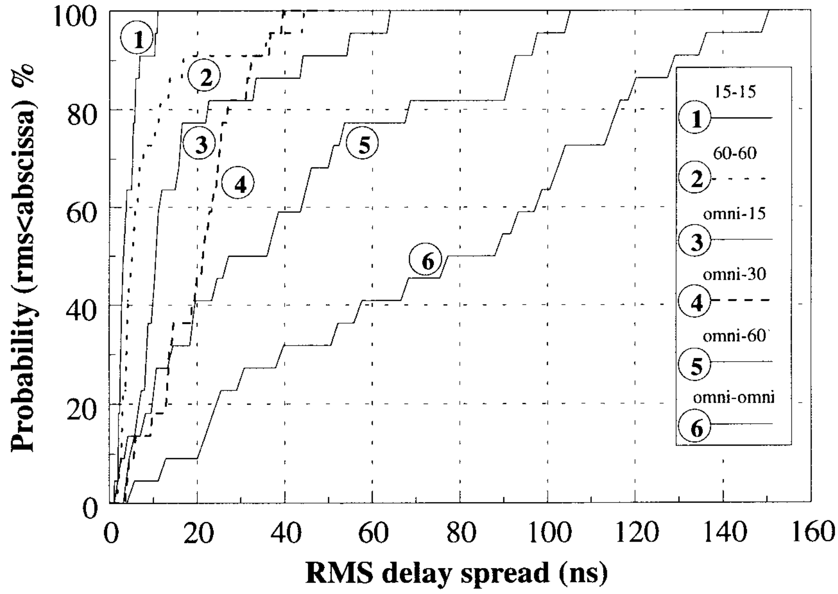


Figure 7: Cumulative RMS delay Spread Distribution (Foyer, figure 6)

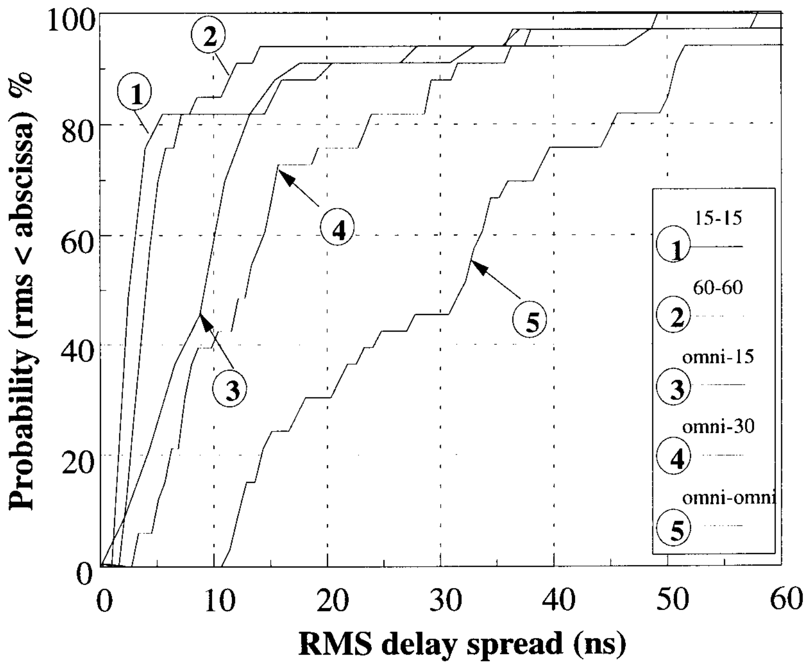


Figure 8: Cumulative RMS delay Spread Distribution (Large Open Plan Office)

For both locations it can been seen that in terms of low rms delay spread, the performance of the 60°-60° arrangement is better than the omni-15° approach, although both configurations have a similar combined gain. Furthermore, the results clearly indicate that low rms delay spreads can be achieved with correctly orientated narrow beamwidth antennas. If an rms delay spread window of 20ns is assumed, then for the Foyer area the 15°-15° configuration achieves 100% coverage whereas the 60°-60° can provide up to 90% coverage. With an omni-antenna at the mobile, a 15° antenna was necessary at the basestation to achieve 75% coverage. For

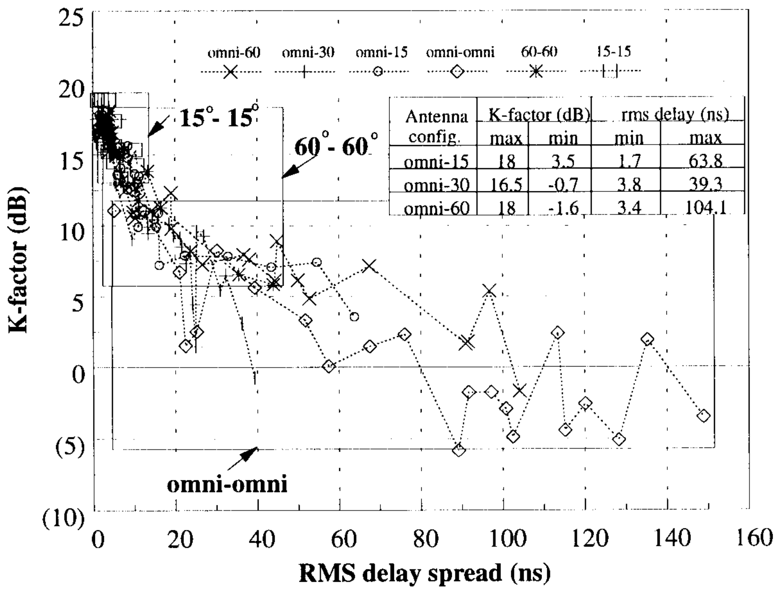
30° and 60° antennas at the basestation, coverage drops to around 40% of locations. It should be noted that all these measurements were taken within 25 m of the BS.

In the large open plan office part of the route taken was blocked by a metal filing cabinet, and hence rms delay spreads in excess of 100ns were measured at some locations. Once again, the rms delay spread measurements confirm that omni-omni antennas can result in very high rms delay spreads (values around 100ns were measured in both cases). For this value of dispersion, it would be difficult to achieve data rates in excess of 1 Mb/s without the use of adaptive equalisation or multicarrier transmission techniques. However, by employing highly directional antennas, 90% of locations were found to have rms delay spreads less than 10ns, thus making higher bit rate communications possible.

7.2 Rician-K factor Analysis

In order to achieve compatibility with Hiperlan type 4 operation, the modem must be able to support data rates of ≥70Mbit/s (assuming TDD operation and a bi-directional user rate of 34Mbit/s). If the classical Rayleigh model is assumed for multipath activity, then a single carrier QPSK based non-equalised modem could only operate where the rms delay spread was less than 2.9ns for a bit error rate threshold less than 0.1%. However, modems employing directional antennas to combat multipath activity are known to offer data rates well in excess of 70Mbit/s when operating in environments with rms delay spreads far higher than this value. Thus, the use of the Rician K-factor has been considered here to further characterise the environments, since this measure is ideally suited to channel conditions where a stable line of sight component exists.

In order to further understand the relationship between the rms delay spread and the Rician K-factor, figure 9 was produced. The graph shows that the K-factor remains high (>7 dB) for values of rms delay spread less than 20ns. As the rms delay spread increases, there is a greater possibility of encountering low K-factors, and hence severe fading. For example, with 15 degree beamwidth antennas, the lowest measured K-factor was 12 dB, and the highest rms delay spread was 10ns. However, for an omni-omni configuration, the K-factor can be as low as -6 dB (Rayleigh), and the rms delay spread as high as 150ns. The table within figure 9 shows the extreme K-factors and rms delay spreads for mixed antenna solutions.



Antenna config.	K-factor (dB) max	K-factor (dB) min	rms delay (ns) min	rms delay (ns) max
omni-15	18	3.5	1.7	63.8
omni-30	16.5	-0.7	3.8	39.3
omni-60	18	-1.6	3.4	104.1

Figure 9: Rician K-factor against rms delay spread for Foyer

For digital transmission over line-of-sight channels, it now appears that the K-factor is a more important parameter than the rms delay spread. For example, when the K-factor is high, the received 'eye diagram' remains open at the sampling points irrespective of the time delay spread. For K-factors greater than 8-10 dB, even if the random multipaths add up coherently (which is unlikely), the LOS component will still remain greater than the random component, and hence the 'eye diagram' will remain open. Using this argument, at high K-factors the rms delay spread is not important and the supported bit rate will be determined by the signal to noise ratio. This implies that with sufficient antenna gain and transmit power, for K-factors greater than 8-10dB, very high bit rates (in the region of 155 Mb/s) could be supported by the AWACS architecture.

Based on the results shown in figure 9, the 15°-15° antenna configuration would meet the above K-factor criteria over the 25 metre route considered. However, the omni-15° antenna resulted in a K-factor of 3.5 dB. This implies that for some locations (approximately 30% assuming a worst case Rayleigh distribution), the phasor summation of the random components would result in eye-closure and hence, bit errors. To improve the probability of a favourable channel, simple spaced antenna diversity can be used at the mobile [6]. Assuming two uncorrelated paths, the probability of failure would be statistically reduced to 9%. This implies that very high speed data links can be achieved over our test route with two spaced omni antennas at the mobile and a 15° directional antenna at the BS.

8. Transceiver Evaluation Trials

In order to investigate the relationship between the channel parameters and the corresponding Bit Error Rate (BER) and Cell Loss Ratio (CLR) performance of the AWACS transceiver, an HP ATM test-set was used in conjunction with the hardware described in table 1. For each measurement a 30 second averaging period was used to calculate the BER. Given that the transmission rate of the system is 70Mbp/s, a total of 1.76 million ATM cells were transmitted during each measurement period. Figure 10 shows the variations of the Rician K-factor, RMS delay spread and the BER obtained for the 60°-60° antenna combination when operating along route CDA in the foyer (see figure 6).

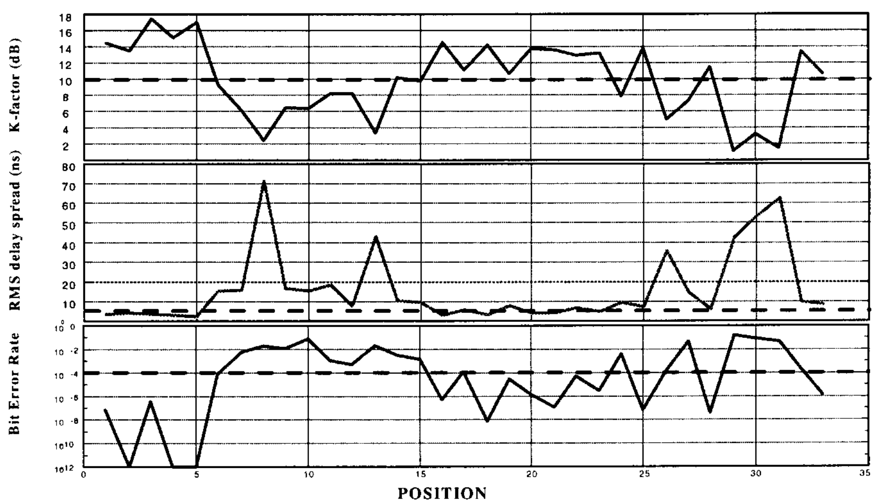


Figure 10: BER and channel parameter variations (60°-60° combination)

It can be seen that generally as the Rician K-factor decreases and the RMS delay spread increases, the corresponding BER performance degrades. However the variation in the system performance can be seen to be more in tune with the changes in the Rician K-factor than the observed RMS delay spread. From figure 10 it can be seen that if the acceptable performance threshold for the system is set at a BER of 0.01%, then provided that the RMS delay spread experienced by the system is less than 5ns and the K-factor is higher than 10dB, satisfactory performance can be obtained throughout the service area for the 60°-60° antenna combination. This suggests that for a given modem, it is possible to determine the required Rician K-factor, power and rms delay spread thresholds necessary to achieve acceptable performance. Using these values, an appropriate antenna configuration can be chosen.

9. Conclusions

In this paper, the AWACS test-bed configuration and specifications have been described together with the frame structures used for the up and down link transmissions. By integrating a channel sounder with the modem, propagation measurements at 19.37 GHz have been obtained for several typical wireless LAN operating environments. The results give a good indication of the propagation characteristics that can be expected in this emerging frequency band. Generally, rms delay spreads varied between 5ns and 150ns (with the lower values being achieved with at least one end making use of a correctly orientated high gain antenna). Values of K-factor have also been measured and it is suggested that for values greater than 8-10dB, the bit rate becomes limited by Signal to Noise rather than rms delay spread.

The results indicate that for radio LAN systems such as the 17 GHz Hiperlan type 4 standard [7], the use of fairly narrow antenna beamwidths can be used in line-of-sight (and some non-line-of-sight) locations as an alternative to adaptive equalisation or multicarrier transmission. The problem of achieving good omni-directional coverage still needs to be addressed. The AWACS project aims to investigate the feasibility of using switched beam antennas at the basestation to solve this problem.

10. Acknowledgements

The work presented in this paper was performed as part of the ACTS-AWACS project and partially funded by the European Commission. The authors would like to acknowledge the help and support of their project partners, namely ALCATEL CIT (C.Evci, A. De Hoz), ALCATEL SEL (R.Rheinschmitt), NTT (M.Araki, M.Umehira), CSELT (S.Barberis, E. Gaiani, B.Melis, G. Romano and V.Palestini) and ELEKTROBIT (H. Hakalahti and M. Tolonen). Particular acknowledgement is given to NTT for providing the hardware test-bed.

References

[1] C. Evci, M.A.Beach & G. Romano, 'AWACS System for Tetherless Multimedia Services', IEEE Workshop on Wireless Multi-media Communications, Kings College, London, 23-24 June 1997, pp1-12

[2] M. Umehira et al., "An ATM wireless access system for tetherless multimedia services", ICUPC '95

[3] D.C.Cox, "Delay Doppler characteristics of multipath propagation at 910 MHz in suburban mobile radio environments", IEEE Trans.on Veh. 1972, AP-20, pp625-635

[4] Y. Sun et al, '19 GHz channel characterisation measurements for future ATM wireless LAN systems', PIMRC'97 Conference Proceedings, Finland, September 1997.

[5] M.A. Beach, A.R. Nix, P. Hafezi & Y. Sun, 'Wireless ATM via the Spatial Domain', Indoor Communications Colloquium, Delft University of Technology, October 1997.

[6] Y.Sun, A.Nix & J.P.McGeehan, 'HIPERLAN Performance Analysis with Dual Antenna Diversity and Decision Feedback Equalisation', VTC'96, April 1996, Atlanta, U.S.A.

[7] Radio Equipment and Services (RES), High Performance Radio Local Area Networks (Hiperlans), Requirements and Architectures for Wireless ATM Access and Interconnection, ESTI, TR101 031, V1.1.1, 1997-04.